P 1.9

IDENTIFYING AND CHARACTERIZING DRIZZLE DISTRIBUTIONS WITHIN MARINE STARATOCUMULUS USING W-BAND RADAR REFLECTIVITY

J.Y. Wang * and B. Geerts
Department of Atmospheric Science, University of Wyoming

1. Introduction

Marine stratus has attracted many researchers' attention in the past two decades. Both experimental and theoretical methods have been used to study the cloud microstructure.

A fixed-beam airborne cloud radar enables 2D measurement of cloud microstructure. Drizzle is prevalent in marine stratus, and may dominate the radar reflectivity. Drizzle can increase the radar return by 10 to 20 dB above the echo due to cloud droplets in extensive marine stratocumulus deeper than about 200 m (Neil and Anthony 1996). This is because Raleigh scattering is proportional to the 6th moment of particle size. Typical concentrations of cloud droplets in marine stratus produce a reflectivity of about –18dBZ, and typical drizzle amounts increase this value to about –5dBZ, assuming Raleigh scattering (Frisch et al. 1995). Due to its low number concentration, drizzle has a negligible effect on LWC or effective radius. How to identify the presence of drizzle with W-band radar reflectivity is the main objective of this study.

The Wyoming King Air and Wyoming Cloud Radar (WCR) examined stratus off the Oregon coast during August 1999. Measurements of in-situ cloud probes are compared with nearby radar reflectivities. The first question is whether a clear threshold value of radar reflectivity exists, above which drizzle is present. Certainly, drizzle was more likely and more numerous when the radar reflectivity, 90 m to the side of the aircraft, was higher.

In **Fig 1** the probability of drizzle (P_Z) at an equivalent reflectivity value of Z is plotted,

$$P_Z = {N_{dZ}}/{N_Z} \qquad (1)$$

where N_Z is sample fraction of reflectivity Z at 75-105 m to the side of the aircraft, and N_{dZ} is the sample fraction with drizzle. Drizzle represents droplets with diameters exceeding 100µm, as measured by the 2DC cloud probe.

Drizzle probabilities in different cloud layers sharply increase in the reflectivity range from –20 dB to –10 dB (**Fig 1**). This implies little uncertainty about a drizzle reflectivity threshold in marine stratus.

The horizontal structure of drizzle patches could be plotted with the threshold reflectivity method. Maps of drizzle patches within and optically rather uniform stratus cloud could provide insight into the dynamics and cloud processes leading to drizzle formation.

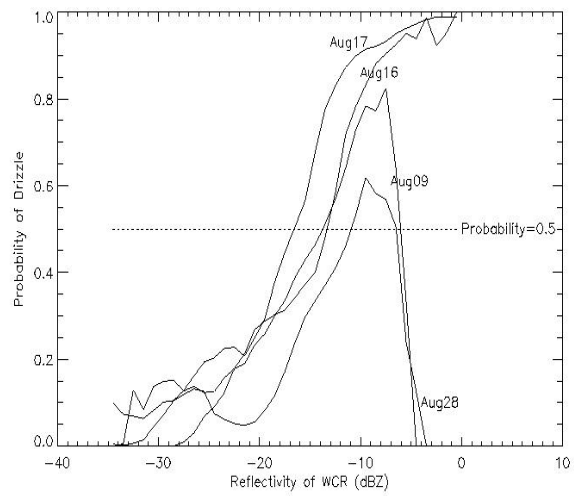


Fig 1. Drizzle's probability corresponding to different reflectivity values for 4 flight days.

2. Data Analysis

The 2DC sample volume is 5 liter, and this sample is collected over 1 second. A minimum of 2 drizzle droplets per sample (0.4 l^{-1}) is assumed to be a minimum for the condition 'drizzle present'.

One problem is that there is a 90m distance between radar second gate samples and the in-situ 2DC measurements. If there are more than 3 seconds of continued 2DC data exceeding 0.4 drops per liter, a drizzle ***patch*** with diameter of at least 300 m is assumed, as the aircraft speed is about 100 m/s. Under this situation, the data of both 2DC measurements and radar second gate samples are considered to reflect characteristics of the same drizzle patch. Similarly, if there are more than 3 seconds continued 2DC measurements equal 0.0 drops per liter, a region with diameter larger than 300 m is considered to have no drizzle. The 300 m distance is much more than 90 m, as a way to account for the non-circular nature of patches with or without drizzle. Sample sequences with/without drizzle less than 3 s (300 m) long are ignored. Hence two series of 2 DC sequences are obtained for every flight, one with drizzle, one without.

* Corresponding author address: Jingyun Wang, P.O. Box 3038, Univ. of Wyoming, WY, 82072; e-mail: wjy@uwyo.edu

Another concern is that radar measurement gives a much higher frequency than that of 2DC probe. Different from the frequency $1s^{-1}$ of 2DC, Radar measurement gives 33 or 34 profiles per second. In this paper, when 2DC measurement is larger than 0.4 l^{-1}, all radar reflectivities received during this second are considered to be produced by both cloud droplets and drizzle drops.

From the observation, both LWC and drizzle presence depend on altitude in cloud, measurement data at different altitudes in cloud are studied. The cloud top and base for the 4 flights, determined by means of the LWC profiles, are summarized in **Table 1**.

Table 1. Altitudes of cloud top and cloud base.

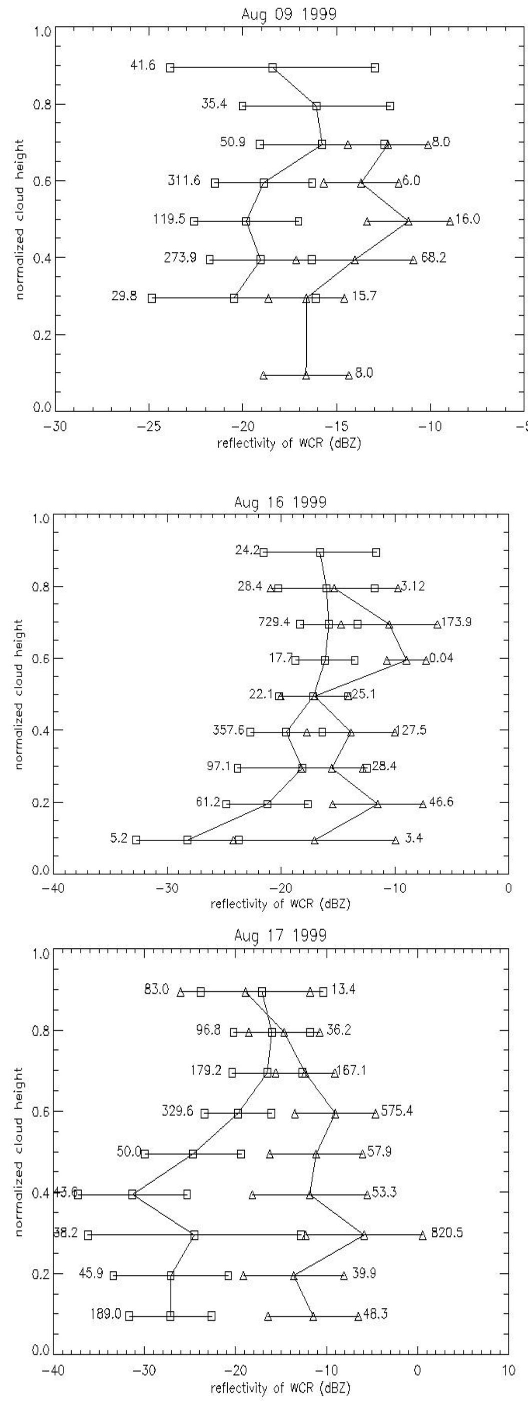
	Cloud Top (m)	Cloud Base (m)
Aug 09th	375	55
Aug 16th	430	130
Aug 17th	800	360
Aug 28th	870	530

All of four days cloud altitudes are normalized. Because of horizontal variances of cloud top altitudes and cloud base altitudes, the top and bottom 5% of the cloud are ignored. The cloud deck, between normalized altitudes of 0.05 and 0.95, is divided into 9 layers. Measurements with/without drizzle belonged to different layers are studied respectively.

The vertical profiles of reflectivities, one with and one without drizzle, are shown in **Fig 3**. Most profiles have the trend of increasing with altitude in cloud. And in most cases there is a clear separation between the two profiles, mainly at low levels within the stratus. One possible reason for the mixing of two profiles at upper part of cloud is that there are fewer radar measurements to present drizzle. For there are seldom drizzle at upper part of cloud, the drizzle patch may be much smaller that that at low level. The 90m distance between in-situ probe and second radar gate brings more uncertainty into data samples at upper part in cloud than that at lower part.

The numbers in **Fig 3** are sample sizes of reflectivities with/without drizzle in each layer. Because the two group reflectivities are decided by 2DC measurements, the sample size use 2DC measurement number in each layer. For sample size is not integer, the radar reflecitivities in one second belong to two layers.

Based on sample sizes in **Fig 3**, larger difference between sample sizes in the same layer or small sample sizes are observed at mixing areas of the two group reflectivities. This may give an explanation for small seperation between the two group data.



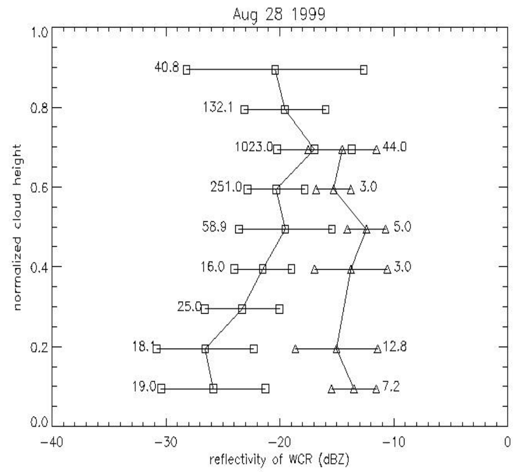


Fig 3. Distribution of WCR radar reflectivity with/without drizzle in five different cloud layers. The cloud height is normalized, from cloud base (0) to cloud top (1). The numbers on left/right are sample sizes of reflectivity with/without drizzle. The unit of sample size is second. Each left point is the reflectivity value exceeded by 84 % (one standard deviation below the mean for a normal distribution). Also shown are the median and the value exceeded by 16 %. Data from four days are shown.

3. Result

Given the rapid increase of drizzle probabilities with increasing WCR reflectivity (Fig 1) and the clear distinction between reflectivity profiles with and without drizzle (Fig 3), a coefficient ***hit rate*** is performed to select a threshold reflectivity indicating drizzle presence. In **Table 2**, a ***2DC Yes*** means a 2DC drizzle drop concentration exceeding 0.4 l^{-1}. The ***reflectivity Yes*** is based on exceedance of a given reflectivity at the first WCR radar gate, 90 m to the side.

Table 2. Contingency table of drizzle decided by 2DC and by radar reflectivity.

Drizzle present	2DC Yes	2DC No	
Reflectivity Yes	n_{00}	n_{01}	$n_{0\bullet}$
Reflectivity No	n_{10}	n_{11}	$n_{1\bullet}$
	$n_{\bullet 0}$	$n_{\bullet 1}$	n

A series of threshold reflectivity values between –25 and –10 dBZ is assumed. The optimal drizzle threshold reflectivity is the one corresponding to the maximum ***hit rate*** (**Table 3**). The hit rate is defined as:

$$H = \frac{n_{00} + n_{11}}{n} \qquad (2)$$

Table 3. Optimal drizzle threshold reflectivity (dBZ).

Cloud layer	Aug 09	Aug 16	Aug 17	Aug 28
0.85-0.95	--	--	--	--
0.75-0.85	--	-13	-15	--
0.65-0.75	-14	-13	-14	-16
0.55-0.65	-17	--	-14	-18
0.45-0.55	-15	-19	-16	-15
0.35-0.45	-17	-16	-22	-18
0.25-0.35	-20	-18	-13	--
0.15-0.25	--	-17	-18	-20
0.05-0.15	--	-18	-19	-18

Chi-square test is used to test results by hit rate. The chi-square x^2 null hypothesis is that the 2DC ***Yes/No*** distribution is independent of the reflectivity ***Yes/No*** distribution. Here x^2 is defined as:

$$x^2 = \sum_i \sum_j \frac{\left(n_{i,j} - \frac{n_i n_j}{n}\right)^2}{\frac{n_i n_j}{n}} \qquad (3)$$

where the n variables are defined in the contingency table (Table 2).

If the calculated x^2 value is larger than 3.8 (at one degree of freedom), then there is a 95% certainty that the two distributions are related. This is the case at all levels on all four flights (**Table 4**). Some cloud layers can't do the calculation of x^2 value. It is because when there is a $\frac{n_i n_j}{n}$ smaller than 5, the chi-square method is not reliable.

Table 4. Calculated x^2 value

Cloud layer	Aug 09	Aug 16	Aug 17	Aug 28
0.85-0.95	--	--	--	--
0.75-0.85	--	17	13	--
0.65-0.75	136	225	534	209
0.55-0.65	200	--	1254	219
0.45-0.55	1020	567	373	273
0.35-0.45	621	482	240	119
0.25-0.35	145	597	147	--
0.15-0.25	--	801	171	120
0.05-0.15	--	53	309	128

Fig 4 summarizes the hit-rate analysis. A equation is derived by least-square regression method.

$$Z = -19.5 + 6.2H \qquad (4).$$

Besides two points in Aug 17, most threshold reflectivities are near to the thick line formed with $Z = -19.5 + 6.2H$. Table 5 gives the fraction of reflectivities larger than threshold value. All fractions of reflectivities with drizzle are larger than 50 percent. Most of them are larger than 80 percent. And for reflectivities without drizzle, all fractions are smaller than 40 percent, most of them smaller than 20 percent.

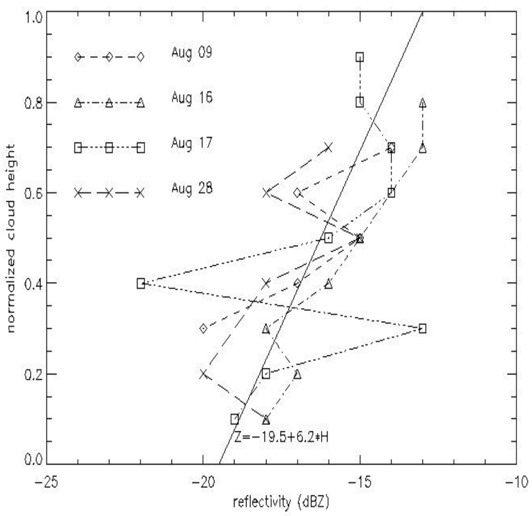


Fig 4. Profile of threshold reflecitivties.

Table 5. Fraction of reflectivity larger than threshold value at each layer (with/without drizzle)

Cloud layer	Aug 09	Aug 16	Aug 17	Aug 28
With drizzle				
0.85-0.95	--	--	--	--
0.75-0.85	--	0.66	0.66	--
0.65-0.75	0.94	0.89	0.86	0.61
0.55-0.65	0.86	--	0.97	0.62
0.45-0.55	0.98	0.48	0.80	1.00
0.35-0.45	0.83	0.78	0.77	0.80
0.25-0.35	0.66	0.89	0.95	--
0.15-0.25	--	0.93	0.87	0.80
0.05-0.15	0.83	0.77	0.95	1.00
Without drizzle				
0.85-0.95	0.08	0.19	0.16	0.04
0.75-0.85	0.23	0.48	0.35	0.03
0.65-0.75	0.38	0.36	0.20	0.28
0.55-0.65	0.16	0.39	0.13	0.04
0.45-0.55	0.11	0.39	0.10	0.19
0.35-0.45	0.26	0.25	0.09	0.00
0.25-0.35	0.20	0.13	0.41	0.02
0.15-0.25	--	0.15	0.11	0.01
0.05-0.15	--	0.00	0.08	0.04

4. Conclusion

Four days a W-band radar and in-situ probes measurements are studied to get the threshold reflectivity of radar for drizzle. Hit rates are calculated to choose the threshold radar reflectivity. Chi-square test is used to test result.

Calculation result shows that threshold radar reflectivity for drizzle increases with cloud altitude. Equation $Z = -19.5 + 6.2H$ derived with least-square method could represent the relation between the threshold reflectivity and altitude in cloud. From table 5, nearly 80 percents of reflectivity with drizzle (decided by 2DC measurements) are larger than the threshold value. And nearly 80 percents of reflectivity without drizzle (decided by 2DC measurements) are smaller than the threshold value.

In Fig 4, there are still a few calculation points have big biases to the think line. The 90m distance between in-situ measurement and 2nd radar gate and small sample size may give some explanation.

With the threshold radar reflectivity, 2D distribution of drizzle in cloud could be plotted. Through combining with other research methods, the formation, development and dispersion of drizzle are hopefully got more understanding.

References

Frisch, A.S. G. Feingold, C.W. Fairall, and J.B. Snider, Measurement of Stratus Cloud and Drizzle Parameters in ASTEX with a K_α-Band Doppler Radar and a Microwave Radiometer. J. Atmos. Sci., 52, 2788-2799.

Neil I. Fox and Anthony J. Illingworth, The Retrieval of Stratocumulus Cloud Properties by Ground-Based Cloud Radar. J. Applied meteorology, 36, 485-492.

Wilks, Daniel S. 1995: ***Statistical Methods in the Atmospheric Sciences.*** Academic press.